Patients Have Two Eyes!: Binocular versus Better Eye Visual Field Indices

Ryo Asaoka,1,2 David P. Crabb,1 Takehiro Yamashita,2 Richard A. Russell,1,2 Ya Xing Wang,2 and David F. Garway-Heath1,2

PURPOSE. To test the hypothesis that better eye measures overestimate binocular visual field (VF) defect severity in glaucoma.

METHODS. Humphrey VFs (24-2 SITA standard) from 67 consecutive patients with glaucoma were retrospectively examined (mean age, 65 years; range, 31–88 years). The better mean deviation (MD) from the two eyes was recorded (better eye MD). Binocular integrated visual field (IVF) was constructed for each patient by merging corresponding sensitivity values from monocular VF. An IVF MD was calculated from the average of total deviation values in the IVF. The differences between better eye MD and IVF MD were assessed.

RESULTS. The average IVF MD was significantly better than the average better eye MD (mean difference, 1.3 dB; 95% confidence interval [CI], 1.0–1.7 dB; P < 0.001). Twenty-four percent of patients had an IVF MD that was at least 2 dB healthier than the MD in the better eye (95% CI, 14%–34%). The size of the differences between better eye and IVF MD was significantly associated with the severity of VF defect (P < 0.001; \( R^2 = 0.44 \)).

CONCLUSIONS. Monocular measures, such as better eye MD, can give the impression that a patient’s VF loss is more degraded than it might be under binocular viewing. This effect is more pronounced in patients with advanced VF defects. The IVF offers a rapid assessment of a patient’s binocular VF severity without extra testing. (Invest Ophthalmol Vis Sci. 2011;52:7007–7011) DOI:10.1167/iovs.11-7643

Quality of visual life (QoVL) can be defined as the sense of personal satisfaction with the conditions in which one lives and functions and how that might be affected by visual impairment. There is good clinical and research evidence to indicate that QoVL is impaired in patients with glaucoma.1–10 Previous reports have specifically shown that, in addition to visual acuity,11–15 visual field (VF) loss impacts the QoVL of patients.12–15,17,18,20,21 Moreover, it has been reported that VF defects in glaucoma can influence hand-eye coordination,14 can increase the likelihood of falling,15 and can increase the risk for causing or being involved in a motor vehicle accident15–19 likely because of an inability to detect peripheral obstacles and hazards.17,20 Because people use both eyes together, a binocular measure is likely the best way to predict the impact of VF impairment on a patient’s QoVL,21 and there is evidence to support this.22 Some studies report a strong relationship between patient QoVL and binocular VF using the Binocular Esterman VF test.2,10,22–26 The Binocular Esterman VF test can be measured with an automated visual field perimeter (Humphrey Field Analyzer [HFA]; Zeiss-Humphrey Systems, Dublin, CA) and a full-field Goldmann perimeter (Octopus 900; Haag-Streit, Koniz, Switzerland). However, in clinical settings, VF scores are dedicated to monocular assessment, and binocular testing is rarely carried out. The integrated VF (IVF) offers an alternative assessment of a patient’s binocular VF severity.27–30 The IVF is estimated simply from monocular results, taking the best sensitivity values from corresponding VF locations from the two eyes, and requires no extra testing. The IVF has been shown to agree closely with the Esterman test in identifying patients with glaucomatous central defects27 and has also been used to predict patients with glaucoma who fail the standard adopted in the United Kingdom for the VF component for fitness to drive.28,30 In addition, a measure based on the IVF has been shown to be more closely related to the perceived difficulty with visual tasks in patients with glaucoma than a measure from the Esterman test.29 Other studies of QoVL have also used the IVF approach for quantifying VF loss,22,30–35 and other investigators22,36 have assessed the merit of this approach.

A direct comparison between monocular VF global indices, such as mean deviation (MD), and those from IVF has not been carried out. This study, therefore, examines the hypothesis that the MD in the VF of the better eye (better eye MD) underestimates a patient’s visual function compared with the MD derived from the IVF. Binocular measures may be more reflective of VF impairment experienced by the patient and might be more pertinent when examining the association between VF and QoVL.

MATERIALS AND METHODS

Sixty-seven consecutive patients in a normal tension glaucoma clinic at Moorfields Eye Hospital were examined retrospectively. The study design conformed to the tenets of the Declaration of Helsinki. Criteria for subject inclusion were visual acuity better than 6/12, refraction <5 diopter ametropia, no previous ocular surgery except cataract extraction and intraocular lens implantation, open anterior chamber angle, and no other posterior segment eye disease.

VF testing was performed using the HFA (model 640 with Statpac-2; Zeiss-Humphrey Systems) 24-2 SITA standard strategy, with the Goldmann size III target. Near refractive correction was used, calculated according to the subject’s age by perimetric software. HFA reliability criteria using fixation losses <25% and false-positive responses <15% were applied. The false-negative rate was not used as an indicator of test reliability.37 All patients had a glaucomatous VF defect in at least one eye, as defined by three or more contiguous total deviation points...
at $P < 0.05$ or two or more contiguous points at $P < 0.01$, a $10$-dB difference across the nasal horizontal midline at two or more adjacent points, or Humphrey MD worse than $-5$ dB. For the purpose of this study, MD was not taken directly from the HFA printout but was calculated for each VF by computing the mean of the individual total deviation (TD) values, excluding the two most nasal points because they are not represented in the VF of the fellow eye, and the two points corresponding to the blind spot region. For each patient, the better MD value from the two eyes was then defined as the better eye MD.

An IVF was constructed for each patient by merging monocular VFs using the “best sensitivity” method. In short, each location in a monocular VF has a corresponding spatially coincident point in the VF of the fellow eye in binocular viewing (apart from the two most nasal points). The maximum raw sensitivity (dB) and best TD (least negative) value from each of the two overlapping locations was determined to give an estimate of the sensitivity and TD at that point, as if the subject were viewing in the binocular mode, excluding the two most nasal points. Given that the IVF sensitivity at the location of the blind spot of one eye is determined by the retinal sensitivity at the corresponding location in the other eye, these points were not excluded. An IVF MD was then calculated as the mean of the individual binocular TD values. In addition, grayscale representations of IVFs were generated for each patient using the IVF procedure in VF software (PROGRESSOR; Moorfields Eye Hospital, London, UK/Medisoft Ltd., Leeds, UK). Differences between values for better eye MD and IVF MD for each patient were evaluated with a paired $t$-test, Bland-Altman plots, and correlation coefficients. Analyses were performed with statistical software (Medcalc, version 11.4.2.0; MedCalc, Mariakerke, Belgium).

**RESULTS**

Characteristics of the study population are summarized in Table 1. The average IVF MD (mean, $-4.1$ dB; range, $-17.1$ to $1.9$ dB) was significantly better than the average better eye MD (mean, $-5.4$ dB; range, $-20.7$ to $1.3$ dB) (paired $t$-test, $P < 0.001$; 95% confidence interval [CI], $1.0$–$1.7$ dB).

The IVF MD tended to be “healthier” than the better eye MD in most cases, as shown in the Bland-Altman plot (Fig. 1a). VF grayscales are shown for three cases in Figure 1b. In many patients, the difference could be considered to be clinically significant. For example, 24% of the sampled patients had an IVF MD that was at least 2 dB healthier than the better eye MD (95% CI, 14%–34%). This effect became more pronounced in patients with more damaged VFs. For example, there was evidence of a significant linear association between the differences of the better eye and IVF MDs and the severity of overall VF damage (Pearson’s correlation coefficient, $P < 0.001$, $R^2 = 0.44$) (Fig. 2a). In addition, three sample cases, exhibiting large discrepancies between IVF MD and better eye MD, are shown in Figure 2b.

**DISCUSSION**

In this sample of consecutive patients from a normal tension glaucoma clinic, a summary measure of overall visual field sensitivity loss (MD) was often found to be better in a binocular measure of the VF than a monocular measure in the better eye. The average difference between IVF MD and better eye MD was statistically significant, and, for approximately one-fourth of the patients in this sample, the difference was greater than a clinically significant amount of 2 dB. There was significant correlation between the magnitude of the difference and the severity of overall VF loss, suggesting that the effect was greater with patients exhibiting more advanced VF loss. The effect appeared more pronounced in those patients with asym-

**TABLE 1. Characteristics of the Study Participants**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y, mean ± SD (range)</td>
<td>65.3 ± 11.8 (31 to 88)</td>
</tr>
<tr>
<td>Male/female ratio</td>
<td>23:44</td>
</tr>
<tr>
<td>Ethnicity</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>42</td>
</tr>
<tr>
<td>Black</td>
<td>15</td>
</tr>
<tr>
<td>Asian</td>
<td>10</td>
</tr>
<tr>
<td>MD of right eye, dB, mean ± SD (range)</td>
<td>$-8.3$ ± $7.0$ ($-25.7$ to $0.4$)</td>
</tr>
<tr>
<td>MD of left eye, dB, mean ± SD (range)</td>
<td>$-7.9$ ± $6.0$ ($-25.2$ to $1.1$)</td>
</tr>
</tbody>
</table>
metric patterns of VF loss between eyes, as illustrated in the cases shown in Figure 2b.

Concordance in defective visual field locations between right and left eyes has been shown to be lower in patients with advanced disease than in those with early-stage disease.39 Between-eye irregularity of defective VF points can lead to a mosaic-like binocular VF, with a mixture of right eye and left eye sensitivity, and this seems well estimated by the IVF. These observations clearly contribute to the finding that significant differences are apparent between the IVF MD and the better eye MD, especially in some cases.

The IVF MD was slightly worse than the better eye MD in 10 subjects, and this might seem odd given that the IVF always takes the maximum sensitivity at corresponding right-left eye VF points. The explanation is found in the contribution to the IVF of the two points from the worse eye that overlap the region of the blind spot of the better eye; sensitivity values at the blind spot are excluded in the calculation of the better eye MD.

IVF is not the same as testing a patient’s VF with both eyes open. IVF only simulates a binocular VF by merging monocular VFs and is, therefore, not “real” binocular testing. Even so, the IVF offers clear practical advantages over an actual binocular test such as the Esterman test because it requires no extra testing for the patient. Moreover, the strategy used in the Esterman test has been shown to give biased results, produces only a pass-fail at each test point, and includes no direct monitoring of fixation, contrary to the procedure in monocular VF testing.27,28 IVF values have been shown to have good concordance with binocular Esterman defects,26,36 and one study has shown that a summary measure of the IVF provides a better prediction of a glaucoma patient’s perceived disability with everyday tasks than a score from the Esterman.29 It is also worth noting that constructing an IVF is not limited to one form of VF testing; the same principle can be applied to monocular VF results from perimeters other than the HFA.

A number of studies examining QoVL have used monocular VF indices in the better eye as the overall estimate of patient VF impairment, and some have shown greater association between QoVL and monocular VF indices in the better eye than those derived from the worse eye.5,11,12,33 though findings from one study contradicted this.32 In practice, clinicians usually focus patient management decisions on the better eye, thinking that that the QoVL of a patient is more dependent on the better VF. Results from this study suggest that in many cases the patient’s functional binocular field of view is likely better than that represented by the better eye VF alone, particularly if VF loss is advanced and certainly where there is spatial discordance in between-eye VF damage. It seems sensible that studies designed to investigate the association between QoVL or everyday function against VF loss would do well to consider summary measures from a binocular measure such as the IVF. Some studies have already taken this approach31,35 (merging results from monocular VFs), and others have considered bilateral measures of visual impairment (VFs and visual acuity) when exploring the functional impact of impairment on QoVL in glaucoma.29

Each point in the IVF is constructed using the maximum sensitivity (dB) value from each of the two corresponding monocular locations. Nelson-Quigg et al.36 examined alternative calculations for generating binocular sensitivities from monocular results, comparing them with a reference standard of a full-threshold HFA VF performed on a patient with both eyes open. The results indicated that a summation method (calculated by the square root of the summed squares of the two monocular sensitivity values), when compared to the maximum sensitivity method (as used in the IVF), gave a better prediction in more patients, but the difference was small and not statistically significant. In practice, there might be little advantage in using a summation method as an alternative to the maximum sensitivity, given the level of noise within VF testing. This is supported by previous work on the IVF when using a binocular Esterman VF test, or a patient’s perceived performance on functional tasks, as a reference standard.22,27–29

The present study was not designed to test a method for combining monocular VF results to form an IVF because a reference standard for the binocular VF was not assessed. Still, it is noteworthy that binocular sensitivity calculated using a sum-

---

**Figure 2.** Comparison of IVF MD and better eye MD in patients with large discrepancies between IVF MD and better eye MD. (a) Bland-Altman plot of IVF MD and better eye MD with simple linear regression line superimposed on the trend, indicating that differences between the two measures become more pronounced as average VF damage increases. (b) Grayscale images of monocular (HFA printout) and binocular (VF software) IVFs for three sample cases (as labeled on the plot) where there is a large discrepancy between MD values. "Better eye."
mation method will, by definition, always be better than, or at least equal to, the maximum sensitivity of the best eye. Therefore, the main finding from the present study—that is, monocular measures such as better eye MD can give the impression that a patient’s VF loss is more degraded than it might be under binocular viewing—would remain unaltered even if the IFV used a summation calculation. Nevertheless, further investigation into the best method for combining VF information from the two eyes would be helpful, possibly considering other models for a potential binocular summation effect and perhaps also considering issues of binocular rivalry or ocular dominance.

In conclusion, this study provides evidence that IVF MD is typically more preserved than the MD of the better eye, particularly in patients with more advanced VF defects. Many patients’ fields of view might be less impaired than would be expected considering monocular measures alone, even in the better eye. The finding reported in this article should encourage those designing studies to examine the association between VF loss and QoVL to use IVF type measures rather than per eye measures. Careful interpretation of monocular VFs, and the indices derived from them, is needed when predicting the impact of functional impairment in patients with glaucoma, particularly in those at more advanced stages in the disease process; the integrated visual field might be a useful clinical tool in such circumstances and would be a useful and easily implemented addition to VF analysis software.

References